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Novel Processing of 81-mm Cu Shaped Charge Liners

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Abstract

A seven-step procedure was developed for producing shaped charge liner blanks by back extrusion at liquid nitrogen temperatures. Starting with a 38.1-mm diameter, 101.6-mm long cylinder at 77K, three forging steps with a flat-top die are required to produce the solid cone while maintaining low temperature. The solid cone is forged in four individual back extrusions at 77K to produce the rough liner blank. This procedure is capable of being run in batch processes to improve the time efficiency.

Introduction

Conical shaped charge liners can be fabricated by a number of techniques including back extrusion, spin forming, electrodeposition, or vapor deposition. Each of these processes has advantages and disadvantages in regard to quality of microstructure, purity, cost, or time. For example, spin forming produces a cone of final shape and thickness but imparts microstructural texture that results in jet rotation. Electrodeposition is a rather slow technique that often suffers from higher impurity levels or larger grain size. High purity liners can be produced by vapor deposition, such as sputtering, but the process is time consuming. Other deformation processes can also be used, but they generally require more steps and tooling changes than back extrusion. Back extrusion is a straightforward process, relatively inexpensive, but requires final machining and produces liners with moderate grain size.

An increase in shaped charge performance can be achieved by improving the design or improving the microstructure. Grain size reduction and lowering the impurity content are two well-established methods of increasing performance. This investigation focuses on reducing the grain size through novel processing methods in conventional, 81-mm, high precision copper shaped charge liners made from oxygen-free electronic (ofe) copper.

Background

A typical two-step back extrusion process begins with a 38.1-mm diameter, 101.6-mm long cylinder with a 21° chamfer on one end. The cylinder is first forged with a flat-top die to a solid cone. The flat-top die is replaced with an inner-contour conical die for back extrusion. Both the forging to a solid cone and the back extrusion to the rough liner blank shape are performed in a single operation each. The liner blank is then given a recrystallization anneal and machined to final shape. This well-established process results in a 20-μm grain size near the base and a 30-40 μm grain size near the apex.

Experimental results from Korzekwa et al. have shown that significant grain size refinement can be achieved in ofe Cu by deforming the material at low temperatures. Their work demonstrates that grain sizes on the order of 2-5 μm are achieved by strains in excess of 2.0 and temperatures near 77K by compression and rolling. Our objective is to develop a back extrusion forging procedure to maintain low temperatures in the copper part during all stages of the forming process.

Experimental Procedure

Material Selection

A suite of samples was chosen to determine the influence of starting material and forging temperature on the resultant microstructure. The Hitachi ofe 10100 half-hard 38.1-mm bar was characterized with optical microscopy. A micrograph, shown in Figure 1a reveals an average grain size of 125 μm. For comparison, ofe Cu that was cold-rolled at 77K was characterized with transmission electron microscopy (TEM). A TEM micrograph of the as-deformed material shown in Figure 1b reveals the heavily deformed microstructure with fine twins and a subgrain size of approximately 0.25 μm.

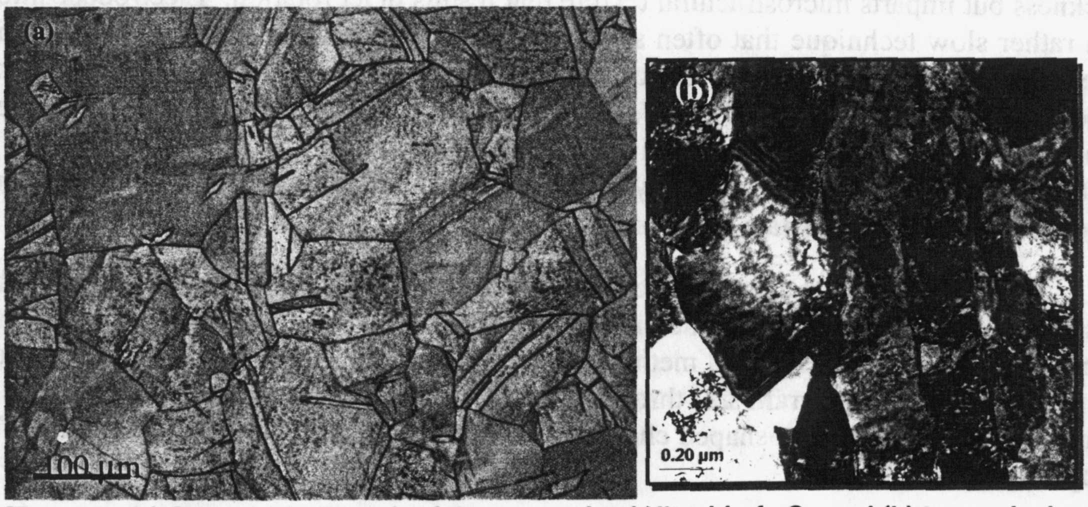

Figure 1. (a) Optical micrograph of the as-received Hitachi ofe Cu and (b) transmission electron micrograph of the copper rolled at 77K.

Additional material in the form of 76.2-mm thick hot rolled plate was machined to 76.2-mm diameter cylinders with the cylinder axis normal to the plate. The cylinders were cooled in liquid nitrogen and extruded in a single step on a 1000-ton press at LANL. The extrusion die had a 120 degree included angle, and the copper billet had a 30-degree chamfer cut to match the die (Figure 2a). The extruded material was not accessible for a direct temperature measurement, but the final temperature was below ambient temperature. The diameter of the extruded rod was 41.9 mm, giving a reduction in area of ~3.3:1, or a true strain of 1.18. The extrusions are shown in Figure 2b. Cylinders for the forging and back extrusion operation were cut from the extrusions. The rods were not annealed after extrusion.

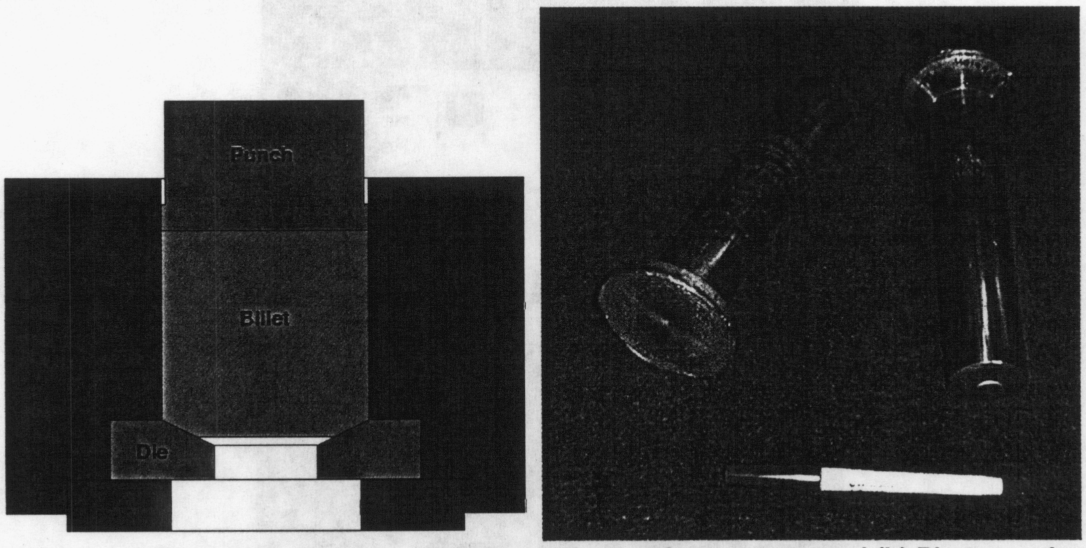

Figure 2. (a) Schematic drawing of the forward extrusion process and (b) Photograph of the ofe copper bar after forward extrusion from 76.2 mm to 41.9 mm.

Back Extrusion

This investigation extends the cold-rolling studies by Korzekwa et al. to the back extrusion process with the objective of reducing the grain size to levels comparable to the cold rolling process. The dimensions of the starting bar are the same as for the conventional back extrusion process, 38.1-mm diameter, and 101.6-mm long with a 21° chamfer. A test matrix was created to evaluate the influence of starting material and process temperature as shown in Table 1.

Table 1. Test matrix.

Material	Processing Condition
Half-hard Cu	Room temperature, 2 steps
Half-hard Cu	Room temperature, 7 steps
Half-hard Cu	Low temperature, 7 steps
Extruded at room temperature	Low temperature, 7 steps
Extruded at low temperature	Low temperature, 7 steps

A 1750-ton press, shown in Figure 3 is used for the back extrusion process. The procedure first involves forging the starting cylinder into a solid cone. For this, a flat top die is used and shown schematically in Figure 4. Figure 5 shows the flat-top die along with the starting cylinder and solid cone after this forging step. The flat-top die is replaced with an inner-contour conical die for the back extrusion process as shown in Figure 6.

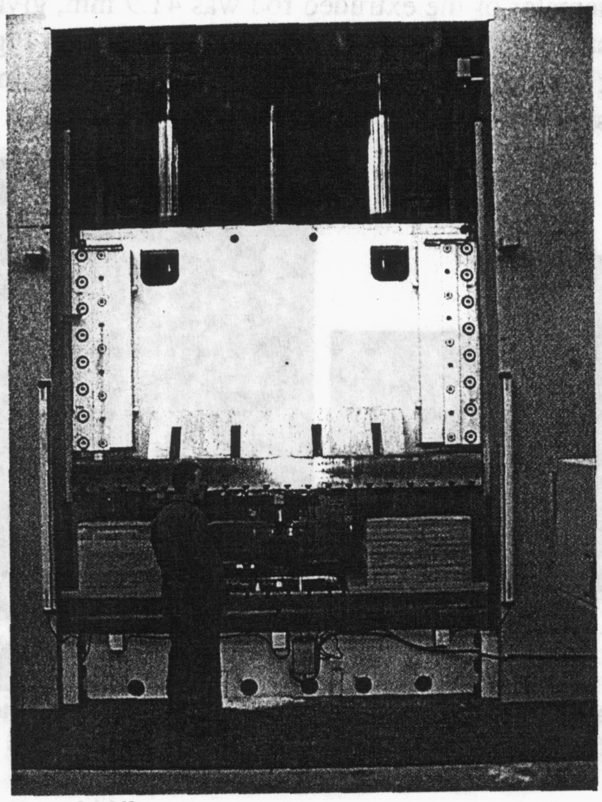

Figure 3. 1750-ton press at LLNL.

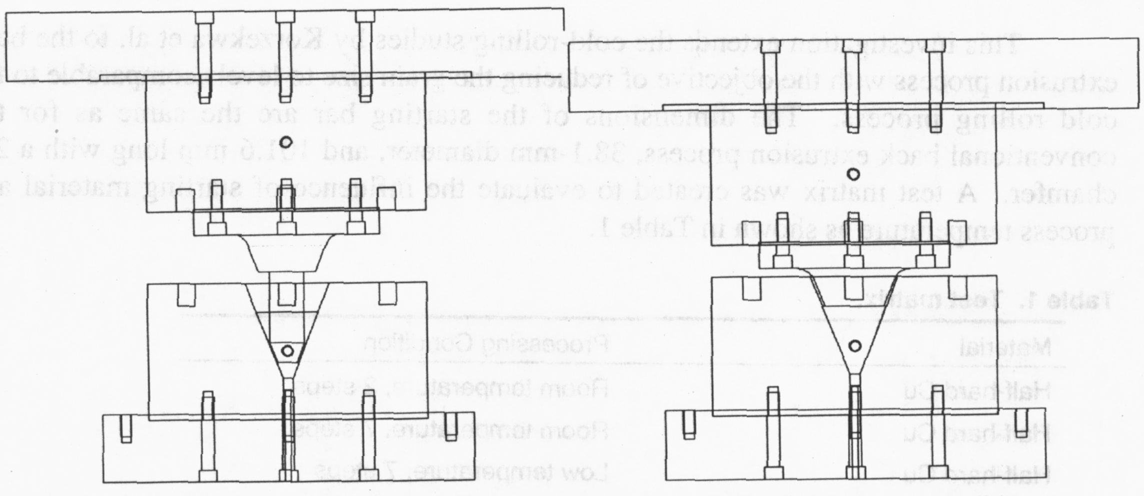

Figure 4. Schematic drawing from the forging of the starting cylinder to the solid cone using a flat-top die.

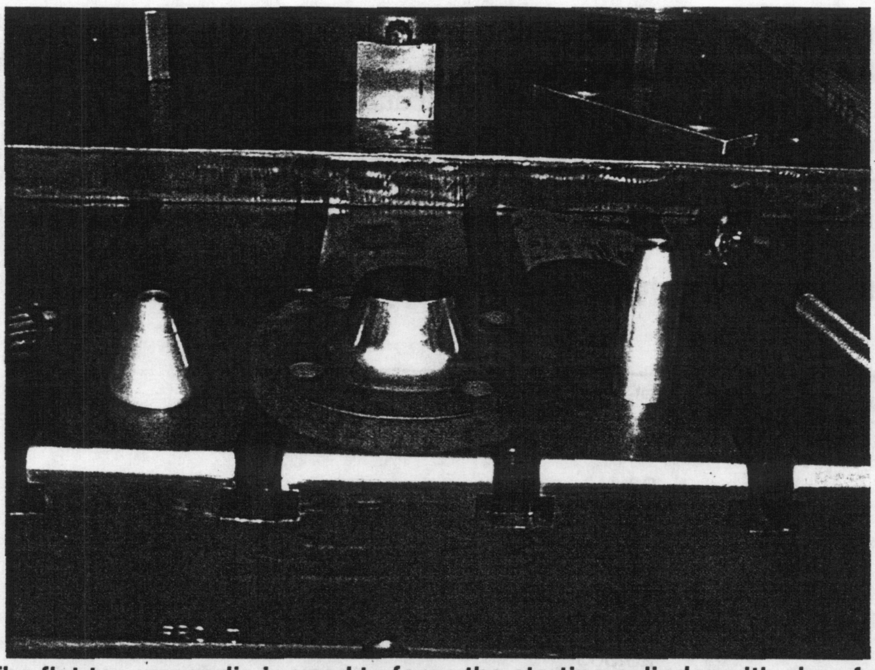

Figure 5. The flat-top upper die is used to forge the starting cylinder with chamfer into a solid cone.

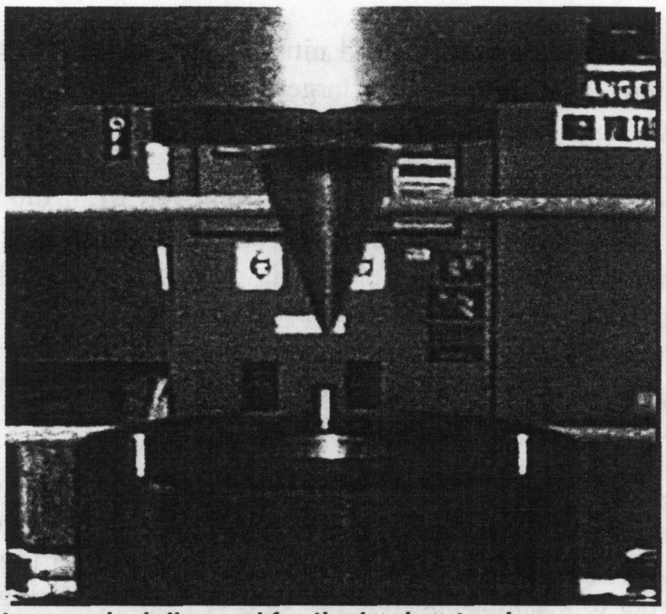

Figure 6. Inner-contour conical die used for the back extrusion.

The forging at room temperature was performed in two stages: forging the solid cone, and back extrusion. At first, each of these stages was performed in a single pass to assure die alignment and proper operation of the press. Starting at room temperature, both the forging to a solid cone and the back extrusion resulted in a significant temperature rise in the specimen. This temperature rise results in a decrease in the stored energy of cold work and thus a subsequently larger final grain size after annealing.

In order to minimize the heating of the shaped charge liner blank during forging, both the forging to a solid cone and the back extrusion processes were divided into partial steps. This multiple-step processing route reduces the amount of specimen heating. The procedure was developed on the half-hard ofe Cu. Separating the forging to a solid cone into 3 steps and the back extrusion to 4 steps significantly reduces the temperature rise in the specimen. Table 2 describes the height reductions of the upper forge platen.

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Table 2. Intermediate height reductions for the multi-step processing.

Step Number	Plunge Depth/Limits (inches)
1	23.6
2	23.1
3	22.62
4	21.0
5	24.065
6	23.565
7	23.050

For back extrusion at near liquid nitrogen temperature, the procedure starts by immersing the starting Cu cylinder in a large liquid nitrogen bath. The time to cool the specimen to 77K is approximately 5 minutes. Once the sample is cooled, it is transferred quickly to the bottom die, leveled, and immediately pressed to approximately one-half the total height reduction. The specimen is then removed from the die and immediately transferred to the liquid nitrogen for cooling. The software program to control the press is modified to allow a greater range of travel. After the specimen returns to 77K, the second pressing operation is done. Again, the specimen transfer is done as rapidly as possible to minimize heating of the sample. The press is again adjusted to the final depth, and the third pressing operation is performed. At this stage, the sample is in the shape of a solid cone, but has not filled the bottom of the die.

The flat-top upper die is replaced with the inner contour conical die for the back extrusion process. One practice forging with the solid cone at liquid nitrogen temperatures heated the specimen to near room temperature during a single pass forging operation. In order to keep the specimen as cool as possible during the forging, the back extrusion process is accomplished in four intermediate steps. The software was programmed to stop at fixed depths to allow transfer to the liquid nitrogen as shown in Table 2. By performing the back extrusion in four steps, the specimen remained cold throughout. Three different starting blanks were forged using this multiple-step procedure; half-hard ofe Cu, ofe Cu forward extruded at room temperature, and ofe Cu forward extruded at liquid nitrogen temperatures. The material that is formed at 77K has a significantly higher strength, as illustrated by the maximum press loads listed in Table 3. This difference in strength is due to both the effect of temperature on the strength at a given condition and the higher work hardening rates at lower temperatures. The difference in press loads is much smaller for the last back extrusion step. The effect of friction on the press load is very large for this step, and the temperature of the workpiece is probably higher because of the thin section of the part and the higher strains imparted in this step. Preliminary microstructural characterization indicates that the half-hard starting material has the largest grain size, particularly in the apex area, whereas the material forward extruded at liquid nitrogen temperatures has the smallest overall grain size. A suite of samples forward extruded from 76.2 mm to 41.9 mm and 102.6-mm long are being prepared for the liquid nitrogen temperature, multiple-step processing into shaped charge liners.

Table 3. Maximum Load in Tons for a Forming Step

Step	LANL Material 77K	LLNL Material Room Temp
1	186	146
2	216	163
3	453	320
4	185	158
5	231	177
6	316	243
7	492	452

Summary

A seven-step procedure was developed for producing shaped charge liner blanks by back extrusion at liquid nitrogen temperatures. Starting with a 38.1-mm diameter, 101.6-mm long cylinder at 77K, three forging steps with a flat-top die are required to produce the solid cone while maintaining low temperature. The solid cone is forged in four individual back extrusions at 77K to produce the rough liner blank. This procedure is capable of being run in batch processes to improve the time efficiency. A batch of liner blanks is currently being produced. The results of the microstructural characterization and the liner performance will be the subject of subsequent reports.

Reference

L.M. Hull and D.A Korzekwa, "Development and Assessment of very Fine Grained Liner Materials", presented at the 50th Bomb and warhead Technical Symposium, LAUR 99-6622.